Mission Concept for a Europa Lander

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Abstract— **A NASA HQ-directed study team led by the Jet Propulsion Laboratory (JPL) with partners including Applied Physics Lab, Marshall Space Flight Center, Goddard Space Flight Center, Langley Research Center and Sandia National Laboratory has recently presented a mission concept for a Europa Lander that would search for bio-signatures and signs of life in the near-subsurface of the Jovian moon. The mission would follow the Europa Clipper multiple-flyby mission, planned for launch in June of 2022, which would provide reconnaissance imagery and other data to the Lander for use in selecting a scientifically compelling site and certifying it for engineering safety. The Europa Lander concept accommodates the Model Payload identified by the Europa Lander Science Definition Team (SDT) and documented in the Europa Lander Study 2016 Report released in February of 2017. The currently envisioned Europa Lander would launch on an SLS Block 1B as early as October of 2025 into a ΔVEGA trajectory, arriving in the Jovian system as early as July of 2030. The baseline design of the integrated flight system includes a dedicated Carrier and Relay Stage, a Deorbit Vehicle composed of a Deorbit Stage consisting of a solid rocket motor (SRM), an MSL-like sky-crane Descent Stage, and a Lander which accommodates the instrument suite. The Lander would be powered by primary batteries over a 20-day surface mission. The science goals envisioned by the SDT require five samples taken from a depth of 10cm, a depth chosen to ensure minimal radiation processing of the potential biomarkers. Mission challenges include the large launch mass, unknown terrain topography, surface composition and materials properties, the high radiation environment, and complying with stringent planetary protection requirements. The mission concept uses a strategy of early risk reduction and overlapping requirements to provide robustness to harsh and uncertain environments. Early risk reduction efforts are aimed at maturing technologies associated with the sampling system, the intelligent landing system, high specific energy batteries, low mass and power motor controllers, and a thermal sterilization system.**

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1. INTRODUCTION

Necessary ingredients for life include water, chemistry, and energy. Since the discovery on Europa of a liquid salt water ocean along with evidence for a relatively young and dynamically-cycled icy surface by the Galileo spacecraft, Europa has become a key target in the search for evidence of life beyond Earth. Europa is tidally locked to Jupiter in a mildly eccentric orbit that provides heat through tidal flexing as an energy source. Chemistry could be available at the interface between the ocean and rocky mantle, analogous to environments on Earth found near hydrothermal vents on the ocean floor that support extremophiles. Another terrestrial model is the algae that live at the base of polar ocean surface ice layers.

Europa “Clipper” multiple-flyby mission (EMFM) would characterize Europa’s habitability as the right first step in the search for potential life at Europa. In spring of 2015 an initial quick-look study reviewed previous Lander studies and targeted a small Europa lander payload augmentation to Clipper. Updates to that initial coupled concept focused on a small, soft lander that would enable in situ science and that relied on Clipper for delivery and relay support to a decreasing degree with each update culminating in a separate launch concept in order to minimize the impact to the on-going project. While NASA is continuing to study options within a cost, risk and science return trade space, this paper describes a baseline concept presented at the Mission Concept Review (MCR) held at JPL in June 2017. In the

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MCR architecture, a Europa lander would launch separately but rely on Clipper for reconnaissance and potentially as a contingency relay asset in the event of Clipper Extended Mission. The mission concept architecture described in this paper assumed a NASA NPR 7120.5E Category 1 and NASA NPR 8705.4 Class A risk category.

2. MISSION CONCEPT ARCHITECTURE

Overview

An overview of a Europa Lander mission concept, which would place a robotic lander onto the surface of Europa as early as the 2031 timeframe, is shown in Figure 1. The lander would be equipped with an instrument suite as described by the Science Definition Team in the Europa Lander Study 2016 Report [1] designed to analyze samples for potential bio-signatures. The lander resources and sampling system would be sized to deliver to the instruments five samples from up to five separate 10 cm deep trenches. The depth minimizes radiation processing and the energy allocation for trenching allows both confirmation of positive indications through repeat measurements in the same sampling site and flexibility to access multiple sites at the targeted depth within the workspace. The primary battery-powered lander would nominally operate for twenty Earth days before depleting its stored energy.

The mission would launch as early as 2025 on a single Space Launch System (SLS) Block 1B Vehicle which uses the Exploration Upper Stage currently in development. Even with the new heavy lift capability of the Block 1B, the large launch mass of a Europa lander, driven by the large ΔVs involved, would require an Earth gravity assist trajectory resulting in a Jupiter Orbit Insertion (JOI) ~ 4.8 years after launch. After an initial Ganymede gravity assist and a subsequent JOI, the spacecraft performs a Perijove raise maneuver to set up the next Ganymede flyby. This begins a series of Ganymede and Callisto gravity assists, referred to as pump-down [2], that would reduce the Europa relative velocity and phase for a particular landing site over the course of 18 months or more. By limiting the gravity assists to Ganymede and Callisto, the spacecraft would avoid the higher radiation environment at Europa throughout the Jovian tour. This sets up the trajectory required for Deorbit, Descent, and Landing (DDL). Requirements on the delivery trajectory would be site dependent and include the delivery velocity and that the local solar time be matched within one hour with that for the Clipper reconnaissance data set in addition to latitude and longitude. The trajectory was also constrained for this concept to be compatible with a 15-minute post-landing communication window and a post-separation burn that returns to Lander visibility within 24 hours and sets up a relay orbit. After an initial transition period the carrier spacecraft would establish a regular, nominally 24-hour, orbit with 10+ hours of visibility to the Lander a day around Europa and serve as a communications relay for the 20+ day surface mission.

Shortly (hours) before landing the spacecraft would separate into a Deorbit Vehicle (DOV) and a Carrier and Relay Stage (CRS). The DOV would execute a guided deorbit burn that reduces the surface relative delivery velocity by a factor of 20 via an ATK STAR-37 solid rocket motor (SRM) that would then be jettisoned. The remaining Powered Descent Vehicle (PDV) would determine its position and velocity using terrain relative navigation (TRN) by comparing Clipper reconnaissance images to images captured by the TRN Camera onboard. The vehicle would then fly to its target using the liquid propulsion system and execute hazard detection using lidar and, if necessary, a subsequent avoidance or targeting maneuver. In the final stages of landing the Lander would deploy its stabilizers and be lowered via tethers by a Mars Science Laboratory (MSL)-

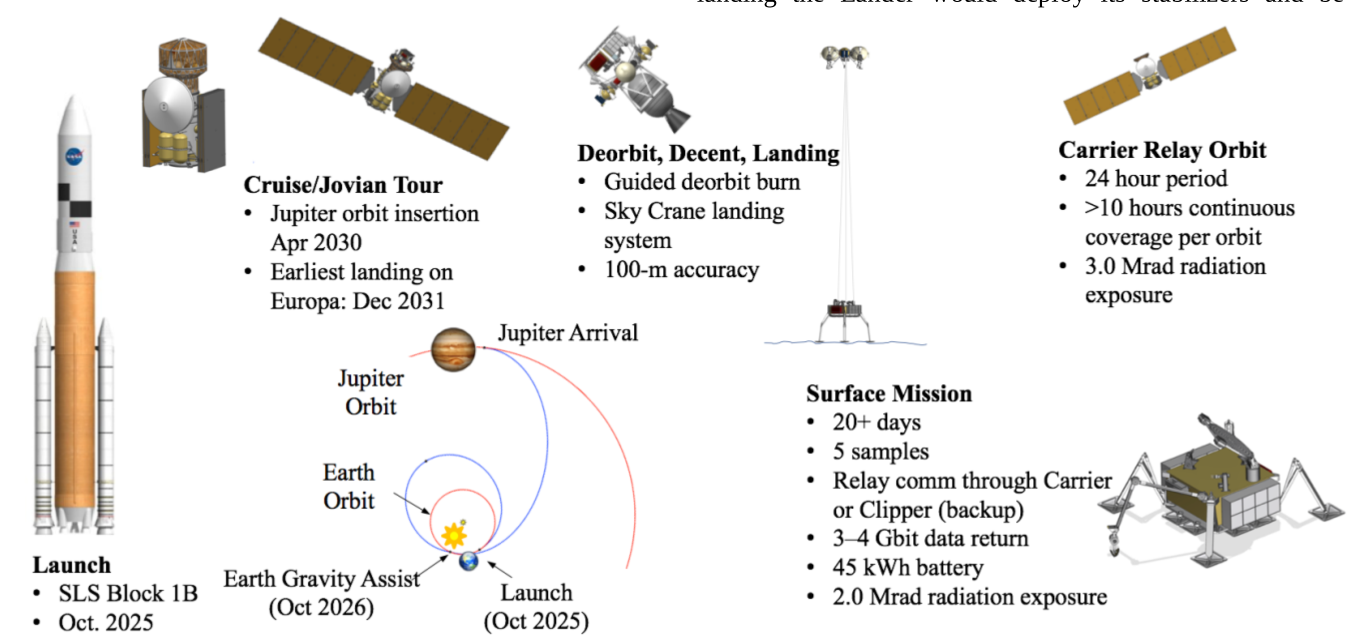

Figure 1. Overview of MCR Europa Lander Mission Concept Architecture and Key Features

derived Sky Crane system on the Descent Stage. Once the stabilizers begin to make contact with the ground, they would conform to the terrain which allows the Lander to stay level. The conforming landing system is designed to be deterministic and testable, rather than, for example, airbags which have complex behavior. When off-load of the tethers is detected the bridle is released and the Descent Stage flies away. Touchdown would be declared once contact of the belly pan of the Lander with the surface was detected, and stabilizers would then be locked in position to provide a stable lander pose.

After touchdown, the Lander would perform health assessments, deployment of the high gain antenna (HGA) and mounted cameras, and initial imaging of the stabilizers, deck and sampling workspace. The Lander would return status and images via the carrier relay asset. Residual DDL data from the TRN camera and hazard detection and avoidance (HDA) lidar provide site context of scientific interest and would also prioritized for return before the carrier sets. The subsequent surface science operations are driven by the urgency associated with the relatively short life-time of the lander compared to that of the recent and on-going landed Mars missions. This drives the need for more autonomy both in the nominal operations including sample acquisition and delivery to instruments, as well as a need to identify faults and take alternate steps so that the system continues to execute the science mission. The science measurements include panoramic imaging, continuous acoustic monitoring with a seismic instrument, and for five in-situ samples analysis of organic composition, microscopic imaging, and spectroscopic analysis.

After the final science data return to the relay stage, when the batteries on the Lander have been depleted fully, a thermal sterilization system within the Lander vault would ignite autonomously and eliminate any remaining viable organisms within the electronics assemblies to comply with the planetary protection requirement to ensure a less than a 10^{-4} probability of a viable Earth organism contaminating a subsurface ocean or other liquid water body on Europa. After the Lander incineration and the data return to Earth have been completed, the carrier stage would be dispositioned into a permanent or temporary parking orbit, or disposed of by impact into Io, Ganymede, or Callisto which would end the Primary Mission.

Flight System

The Cruise Vehicle (CV) in its stowed launch configuration would be comprised of five primary elements as shown in Figure 2 that are combined in different configurations during distinct phases of the mission shown in Figure 3. These elements are the CRS, the Deorbit Stage (DOS), the Descent Stage (DS), the Lander, and the Bio-Barrier. In its launch configuration, the Deorbit Vehicle (DOV), which is the integrated DOS, DS, and Lander, would be fully enclosed within the planetary protection Bio-Barrier with the Lander inverted with respect to its landed orientation. The CRS includes propellant tanks used for the Deep Space Maneuver (DSM), which would be jettisoned after use during cruise.

During the majority of the interplanetary and Jovian tour the spacecraft is in a relatively benign radiation environment; however, after committing to a Europan orbit during the last month before landing following the final Ganymede flyby, the radiation dose rapidly accumulates. Electronics on all elements of the spacecraft that are sensitive to radiation would be shielded within thick vaults on the CRS, DS, and

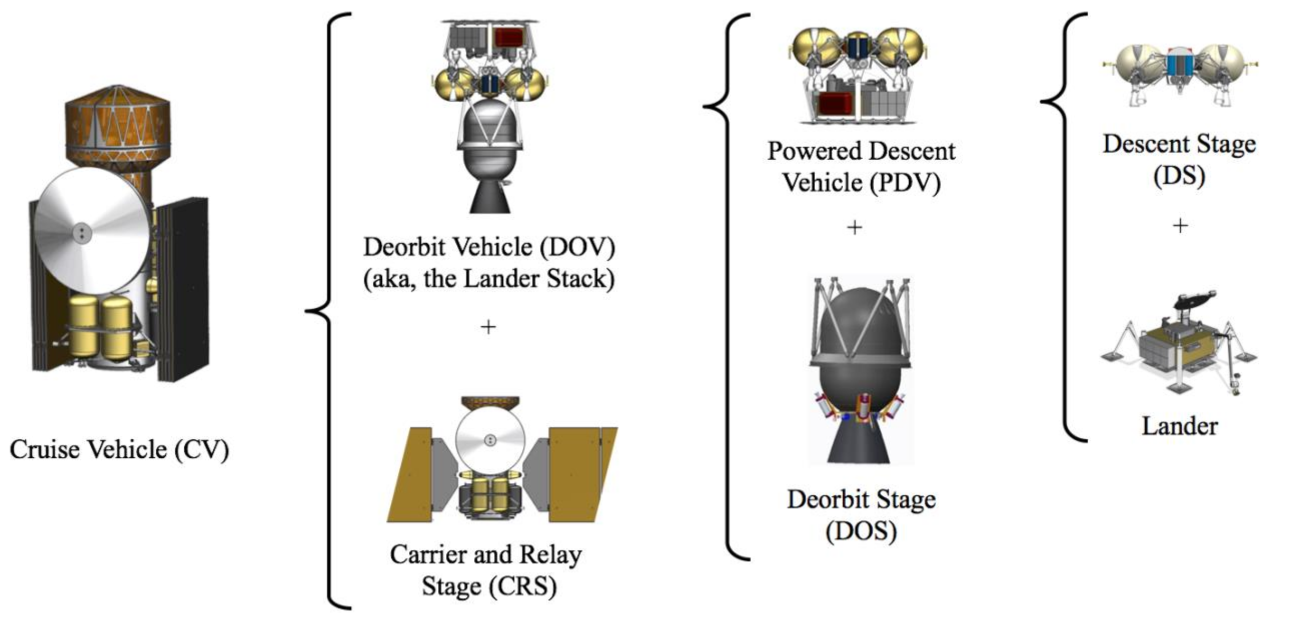

Figure 2. MCR Europa Lander Concept Flight System Nomenclature

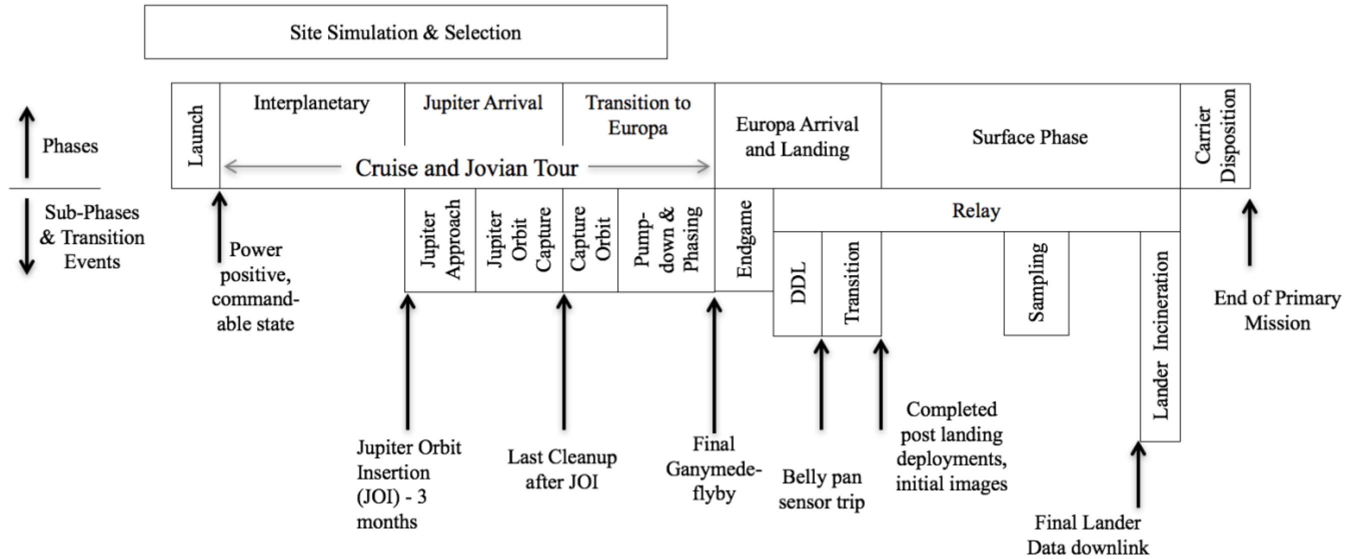

Figure 3. Overview of Europa Lander Mission Concept Phases

Lander. Electronic parts would be selected to be compatible with the resulting shielded environment. Cameras such as star trackers on the CRS, the TRN camera and lidar on the DS, and science cameras located on the Lander would be mounted external to the primary vaults with localized shielding.

The DS is the DDL functional element with dedicated dual string avionics housed in a vault that also serves as the primary structure for the stage. In the MCR concept the stage would include multiple engine sets for thrust vector control during the SRM burn, the attitude control system and descent engines canted to minimize the surface alteration due to plume impingement. The DS would not have a dedicated radio; the Lander radio would be used for DDL communication.

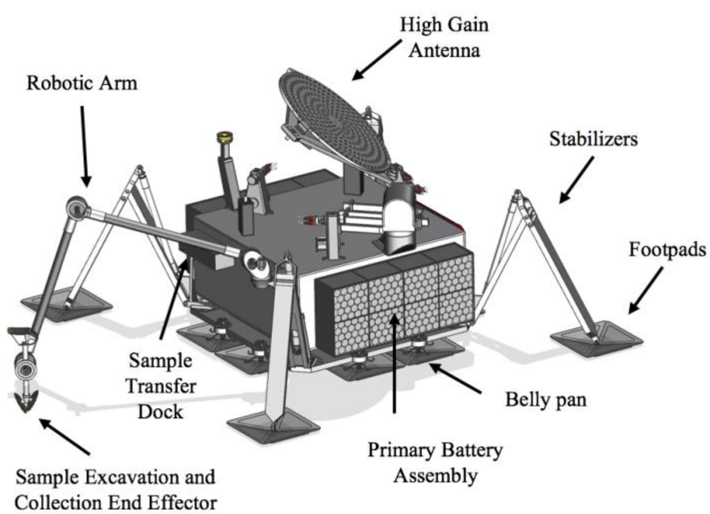

Figure 4. Detailed view of the Lander

The Lander, shown in Figure 4, is designed around a thermally controlled radiation vault that houses the electronics, instruments and other subsystem hardware. The vault would be isolated from the cold Europan environment (with bulk surface temperatures between ~70 K and 130 K) with temperature maintained within flight allowable limits of -40 to +50 °C at the interfaces. The rectangular vault packs efficiently and reduces the surface area compared to a tetrahedral vault. The system would balance radiative heat loss through the vault walls, which is driven by the surface area, with waste heat harvested from the batteries or dissipated within the vault through operating components and, where necessary, heaters. The Lander primary batteries with a Li/CF_x cell chemistry have high cell specific energy (>700 Wh/kg) and are sized to provide 45 kWh. In the landed

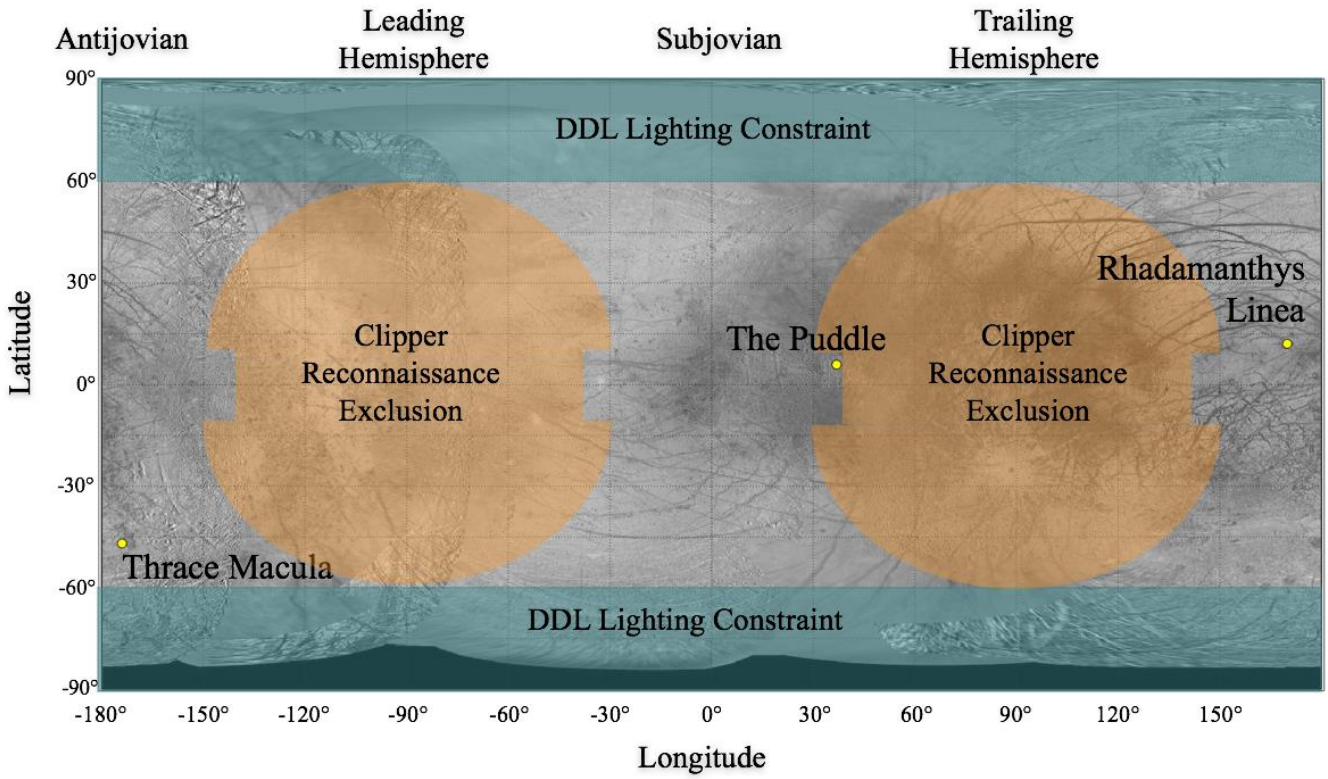

Figure 5. Reference Landing Sites

configuration, the stabilizers attach to the belly pan structure that is thermally isolated from the Lander vault in order to minimize the thermally conductive path to the surface.

The Lander would provide a stable platform level to within ±10° in the presence of terrain relief of up to 1 m. The Lander accommodates fields of view for the HGA and science cameras and allow access for the sampling arm to the workspace. The sampling system would be required to perform all functions at Lander tilts up to ±30°. Due to uncertainties in orientation and materials properties all sample transfer functions would be required to use positive actuations at all points rather than reliance on gravity for sample transfers. Since instruments have not yet been selected, notional volumes consistent with the SDT identified model payload were used to guide the vault layout and size resources. In the concept configuration, all the sample analysis instruments are co-located on one wall of the vault to facilitate sample delivery from the robotic arm to the sample transfer dock for ingestion or observation. This vault layout serves as a proof-of-concept and a starting point for future accommodation of a NASA-selected payload.

The Flight System would have a design lifetime of 10 years in space. The life limiting drivers would be different for the CRS (radiation dose which accumulates quickly while the CRS is in Europa orbit) and the Lander (stored energy in the primary batteries). This mission concept sizes the radiation shielding mass and the primary battery capacity to balance the architecture and provide for the 20-day surface mission.

Reference Landing Sites

Ultimately the landing site would be chosen based on Clipper reconnaissance data which would not be obtained until after launch of Europa Lander. Additional work is required to develop parameterized landing site accessibility maps. For the mission concept development, a small number of relevant reference landing sites were used to explore mission design solutions and to drive out requirements and issues. The selected reference landing sites are shown on the U.S. Geological Survey Europa Voyager and Galileo Solid State Imaging (SSI) Global Mosaic in Figure 5. For the MCR a primary site was designated as a stand-in for a baseline to ensure that the concept presented would be complete with an end-to-end trajectory that met all the constraints and ensure the mission concept was internally consistent, e.g. between the relay visibility windows and the surface operations cadence. The baseline site chosen was Rhadamanthys Linea at 12°N, 170°E, which was imaged by Galileo [3]. Its selection was based on spectroscopic features thought to indicate relatively high abundance of non-ice materials and therefore to be of scientific interest. It also is potentially accessible for Clipper reconnaissance and would not violate known Lander accessibility constraints. Additional sites included Thrace Macula which exhibits chaotic terrain and the "Puddle," a smooth area surrounding a crater as shown respectively in Figure 17 and 13 of [4].

Mission Phases

The mission phases of the conceptual architecture are notionally depicted in Figure 3. Significant aspects of the system engineering would be organized around phases which generally represent all configurations and functions of the project system for a distinct time period of the mission, or for a complex activity representing a significant body of engineering work warranting a dedicated focus. During Pre-Phase A the project requirements document (PRD) has been organized around the phases with the PRD decomposed at the next level to the flight system, mission system and payload system.

The Site Simulation and Selection Phase includes the traditional site selection and certification activities that engage the science community and engineering team to maximize science value while ensuring engineering safety. Clipper currently carries a requirement to provide site certification data sets for ≥ 40 sites over a 2 km x 4 km area at <1 m/pixel spatial resolution. The orange shading on Figure 5 shows geographical regions that are not accessible by Clipper. Desired data sets include stereo imaging at up to 0.5 m/pixel provided by the Narrow Angle Camera (NAC) of the Clipper Europa Imaging System (EIS) and context stereo imagery over a ~44 km x 100 km area at 11m/pixel from the Wide Angle Camera (WAC) to support the Map Relative Localization (MRL) function of the Intelligent Landing System (ILS). The imagery must be collected with a solar incidence angle between 30 and 60 degrees so that the sun highlights the terrain topography. This solar incidence angle requirement restricts the latitude of the landing site to between $\pm$ 60° as shown with blue shading in Figure 4. Radar sounding, altimetry, and reflectivity, thermal inertia and spectroscopy data would also be employed. The Clipper science mission begins in early 2026 with mapping of the antijovian hemisphere with the subjovian mapping completed by the end of 2028. While Clipper reconnaissance capabilities would be understood, the certification data sets collected and provided to Lander ultimately depend on the ground tracks of the selected Clipper tour, pointing locations, and the instrument tasking during that tour which will continue to mature throughout the mission implementation and operations. Representative Clipper ground tracks are shown in [5]. A joint Clipper-Lander reconnaissance planning activity is anticipated. As Europa Lander development would proceed in advance of any Clipper surface reconnaissance, an effort to simulate the Europan environment for the purposes of system design development and ultimately verification, validation and characterization is needed.

The Launch Phase is defined to begin sometime prior to launch, and is complete when the CV reaches a thermally stable, positive energy balance, command-able configuration. It includes launch vehicle separation, establishment of spacecraft attitude, deployment of solar arrays, and establishment of two-way communications and tracking sufficient to predict next communication opportunities. At present this phase also includes any identified unique launch site processing requirements.

Cruise and Jovian Tour that would include the Interplanetary, Jupiter Arrival and Transition to Europa phases along with a number of sub-phases, is defined to begin when the Launch Phase ends, and continue through the final Ganymede flyby when the CV commits to entering the high radiation environment for the last month or so before landing. Significant events during this period would include the release of the bio-barrier, the DSM and subsequent propellant tank jettison, the earth gravity assist and a critical JOI a maneuver. After the CV enters the Jovian system the tour reduces the spacecraft energy and phases to a landing site specific delivery trajectory using Ganymede, and Callisto flybys over more than 18 months. The details of a representative tour, designated trajectory 12L4, are described in [2] shown in Figure 6.

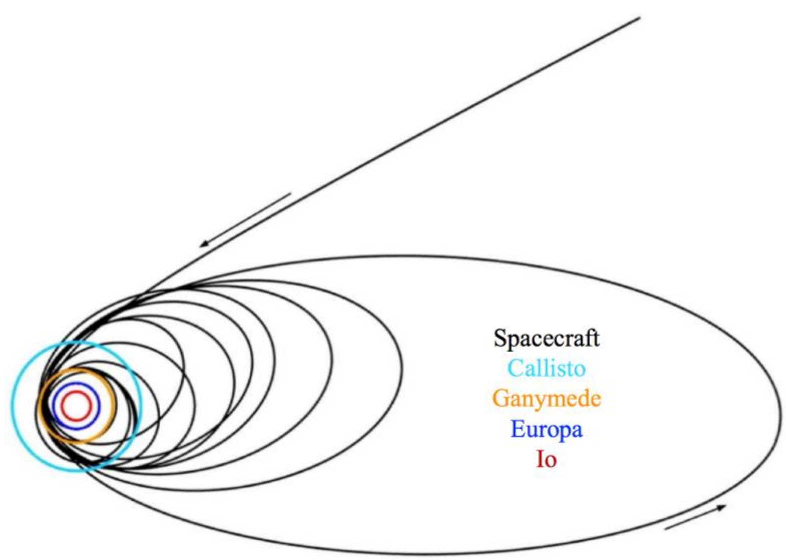

Figure 6. Example Jovian Tour Trajectory

The Europa Arrival and Landing Phase is defined to begin after the last Ganymede flyby, and end when the Lander completes post-landing activities including initial deployments and image collection. During this phase, the CV has committed to the high radiation environment and the ionizing radiation dose is rapidly accruing. For the Rhadamanthys site the reference delivery trajectory takes advantage of the three-body environment which would be used to lower the required ΔV at the expense of requiring a high cadence of orbital trim maneuvers (OTMs). In contrast to the relatively large landing ellipses familiar from Mars experience (e.g. a ~10 km ellipse for MSL driven by the uncertainties in the atmospheric conditions during parachute descent), the ILS navigates to a 200 m diameter landing site chosen so that any 100 m diameter area has a 99% probability of having acceptable landing terrain. The Lander would be designed to tolerate terrain relief of up to 1 m, and the Guidance, Navigation and Control (GN&C) system is designed to ensure the Lander lands on terrain with no greater than 0.5m relief. Overlapping requirements in key performance areas provides system robustness to performance shortfalls and environment uncertainties. The whole DDL sequence, shown conceptually in Figure 7, from before separation through initial landed activities is a many hour critical event. The communication strategy during DDL would be to return critical event telemetry to the CRS for store and forward transmission back to the Deep Space Network (DSN) which would allow event reconstruction in case of failure. After the Lander touchdown, the Descent Stage flies to a safe distance and the DS vault is incinerated per the planetary protection requirements.

The Transition sub-phase provides continuity between DDL and the Surface Phase and includes prioritized data return of backlogged DDL data, including TRN images and the lidar hazard detection map that are of contextual interest for science, and activities to prepare for the first sample including imaging of lander stabilizer, deck and arm and stereo of the workspace for digital terrain map (DTM) construction. This mission concept would be capable of autonomous sampling, but currently would not include utilization of that in the timeline for the first sample. The phase ends with the closing of the post-landing communication window as the carrier sets.

The Surface Phase would include the strategy and timeline for relay communications, panoramic imaging, sample collection and transfer to the instruments, science measurements and operations cadence. After the initial post-landing communication outage, the CRS transitions for the relay to a Distant Retrograde Orbit (DRO), shown notionally in Figure 8, with an orbital period of nominally 24 hours that provides regular 10 hour windows of visibility. When the CRS rises over the 10 degrees on the horizon, communication resumes with forward links commands to the Lander, sampling begins with excavation to 10 cm depth using a

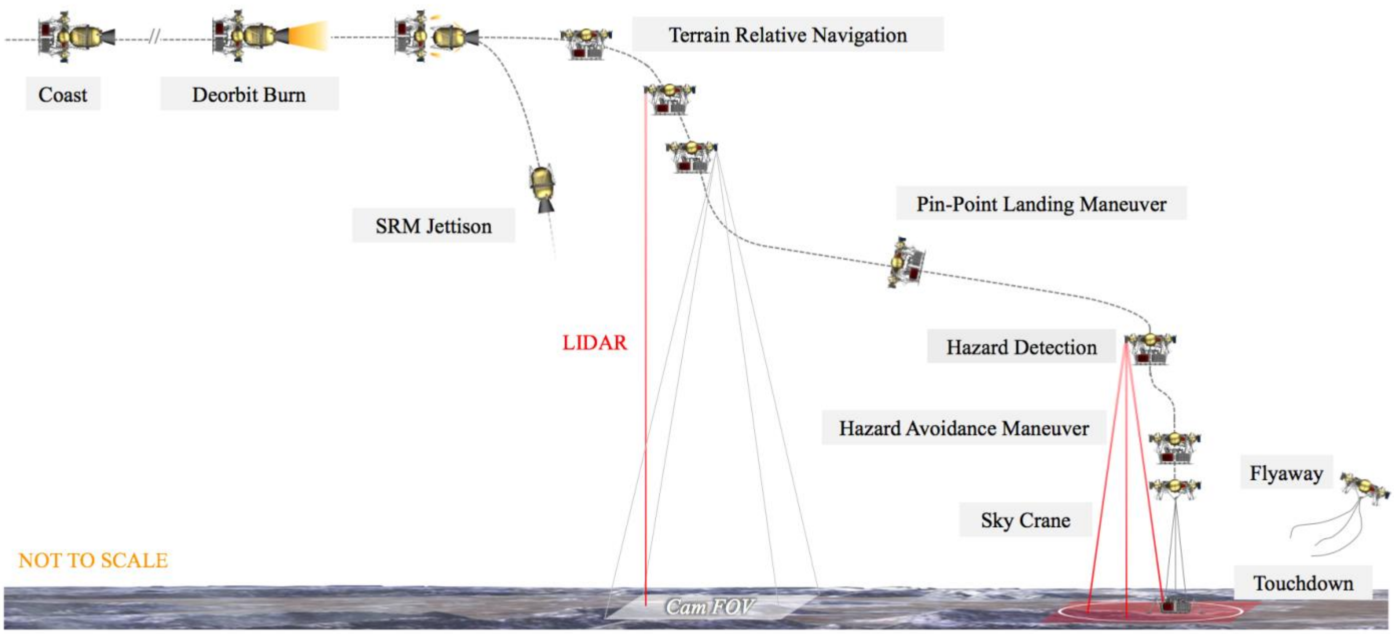

Figure 7. Overview of DDL Concept of Operations

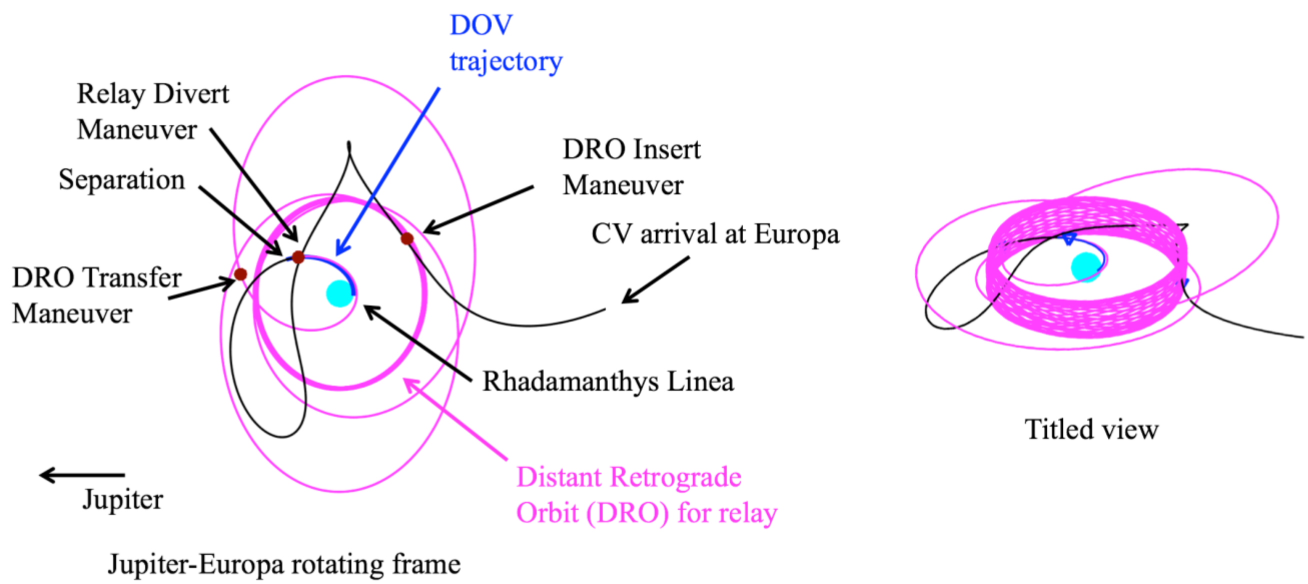

Figure 8. Notional Delivery and Relay Orbit Trajectory

terrain-agnostic counter rotating saw. Once a trench is at the required depth, a Phoenix like rapid acquisition sampling package (RASP) would collect the sample for subsequent transfer or presentation to the instruments. Engineering telemetry would be returned before the Lander avionics would go to sleep to minimize the background energy consumed while the instruments execute their measurements. Once the instruments have completed their analysis, the Lander wakes up and returns the science data and engineering telemetry before the carrier sets. The operations team would have an engineering decisional cycle spanning 24 hours. The science team would plan over a 48-hour cadence to allow assessment of bio-signature presence in the returned data. The presence or absence of bio-signature presence would inform whether to sample in the same site to confirm a positive indication, or move to a new sampling site in the case of a negative. The baseline mission would be resourced to allow for collection of five samples from five different trenches. Given the high cost of background energy use during idle periods, ensuring surface operations can be conducted day or night would be required. Seismic monitoring science would be operating for a minimum of 10 days in parallel with the other activities. To maximize robustness of the system in addition to the stored energy margin on the batteries we also hold a factor of 2 in timeline margin for contingencies. While the Clipper prime mission would have been completed before the Europa Lander surface operations begin, additional capability in the Clipper telecom system is planned that would allow a contingency Europa Lander relay function. The Surface Phase would end when the last data is returned to the carrier, ideally as the last available watt-hour in the batteries is used, and the Lander vault is incinerated.

The final Primary Mission phase would be the CRS Disposition after all science and engineering data from the Lander has been returned. Options for disposition would include parking in an orbit stable to ~35 years, a duration sufficient for accumulating the 10 Mrad required for planetary protection at the most shielded location on the spacecraft, or potentially in a temporary orbit allowing for a future relay capability.

2. DRIVING CHALLENGES AND DESIGN RESPONSES

Launch Mass

While the SLS Block 1B capability allows Clipper to launch into a 2.7 year direct trajectory to Jupiter, the CV at ~16.5 mt would require a ~4.8 year ΔVEGA. The flight system would be designed to minimize interdependence between the stages which would be tested and verified at the implementing institution before being shipped to the launch site for final system integration and test and launch operations.

Surface Topography and Properties Uncertainty

There are significant uncertainties related to the surface topography and materials properties. The limited reconnaissance of the Europan surface available at present, shown in [3], indicates roughness at all scales. In order to maximize the likelihood of finding a certifiable site, the system would be required to access any landing site regions Clipper can access within the previously discussed latitude restriction. This requirement is flowed to mission design to support trajectories capable of accessing those locations and to the Lander TID requirement which is chosen to bound the higher surface radiation regions near the equator on the leading and trailing hemispheres. Even with the highest resolution Clipper reconnaissance data, landing site hazards on the scale of the lander will likely not be visible. The ability to navigate to a pin-point landing combined with the

HDA system that provides a snapshot topographic measurement of a 100m x 100m area within the targeted 200m diameter landing site and chooses the safest site provides a robust capability.

In the absence of detailed landing site characteristics, requirements for the spacecraft and instruments would be based on a set of canonical simulants and topographies developed based on previous remote sensing data, terrestrial analogs, laboratory experiments, modeling of the Europan system or tested materials behavior. For example, Lake Vostok, a subglacial lake in Antarctica, provides a useful science benchmark for total biomass, cell abundances and organic content in accretion ices and glacial ices in a deep polar ocean environment removed from sunlight. Other environments of interest include salt-rich concentrated brines and subglacial liquid water environments. A wide range of engineering analogs would be chosen to reflect one or more potential Europan properties and to provide stressing cases used to evaluate design robustness. For example, terrain analog topographies like the salt pinnacles of Devil's Golf Course in Death Valley could be used to evaluate performance of the ILS sensors and algorithms in field tests under a variety of lighting conditions and derived DTMs could be integrated into a landing simulation. High fidelity contact testing to qualify aspects of the lander engineering design, e.g. for sampling system and landing footpads, would be done at 100 K in vacuum with topographies and ice compositions developed in collaboration with the science team. However, it would be prohibitively time consuming and costly to conduct all development testing in a cryogenic, vacuum environment. The envisioned Europa Lander test program would employ ambient testing of simulants that replicate key materials properties like hardness, toughness, friction, roughness, porosity, etc. to facilitate rapid prototype testing and a broader range of characterization studies.

Jovian Radiation Environment

The high radiation environment around Europa presents a uniquely challenging risk to mission performance and lifetime. Based on the current mission design trajectories, the CRS would accumulate a total ionizing dose (TID) up to 3 Mrad while the Lander would experience 2 Mrad behind 100 mil Al (Si equivalent), primarily from electrons. The mission design trades off radiation dose against the total ΔV required as discussed in [2]. The flight system would employ a number of mitigations including attenuation of the expected dose to 150 krad (Si) for most of the electronics within radiation vaults similar to that used on Juno, and planned for Clipper. All electronics within the vaults must be rated to at least 300 krad in order to maintain a radiation design factor of two (RDF = 2) for additional margin. For the DDL critical event sequence, interrupts in the high radiation environment would be considered nominal rather than a fault, meaning the system must be single fault tolerant in the presence of interrupts.

Planetary Protection

Planetary protection would represent a key requirement for any Europa lander mission and the strategy for compliance involves a number of bioburden reduction techniques. In an ideal case, the entire spacecraft would be subjected to dry-heat microbial reduction (DHMR), a long duration (weeks) bake-out at 125°C or higher in a controlled humidity environment; however, typical flight electronics and other common spacecraft materials could not withstand that treatment. Instead, this Europa Lander concept would use a suite of bio-burden reduction techniques, including standard DHMR wherever possible, penetrating irradiation to 10 Mrad in some cases for example on the batteries, and ultraviolet (UV) irradiation along with specialized handling procedures, alcohol wipe cleaning, seals, covers, filters to prevent recontamination. The DOV would be encased in a bio-barrier and subjected to a vapor hydrogen peroxide (VHP) treatment. Finally, for sensitive electronics encased in the DOV vaults, a high-reliability thermal sterilization system is being developed that would address remaining viable organisms.

3. KEY PROJECT POLICIES FOR ARCHITECTURAL CONCEPT DEFINITION

The project has identified key policies to guide concept development and assessment. The objective would be to articulate and maintain these key aspects of the rationale behind the mission architecture and carry them forward throughout the subsequent implementation and operation of the system, or as appropriate, revisit them and their derivative requirements. Key project policies directed the concept definition team to:

- Maximize inheritance from Europa Clipper including design commonality, use of spares, and reuse of testbeds;
- Partition functions by designing independent flight stages with focused objectives and simple interfaces between delivering institutions;
- Rely on Clipper for reconnaissance rather than providing for a Lander stand-alone reconnaissance capability;
- Maintain capability with Clipper as a contingency relay asset but do not rely on it;
- Employ autonomy for urgent and mission-critical activities;
- Maximize Surface Phase resource utilization;
- Require capability overlaps to reduce risk and mitigate potential development shortfalls;
- Employ functional redundancy to avoid common-mode failures on both science and engineering systems where possible;
- Include cross-strapped, redundant systems.

4. CONCLUSIONS

The Europa lander pre-project team has established a robust mission concept that satisfies the SDT's science objectives and accommodates the model payload. Exploration of the science, architecture and cost trade space surrounding this concept is ongoing.

ACKNOWLEDGMENTS

This mission concept response to the Europa Lander Science Definition Team's identified science investigations and model payload represents the combined work of the Europa Lander Project Team that spans many individuals at multiple institutions as captured in the Europa Lander Science Definition Team 2016 Study Report contributors list.

The information in this paper is pre-decisional and is presented for planning and discussion purposes. The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

[1] Hand, K.P., Murray, A.E., Garvin, J.B., Brinckerhoff, W.B., Christner, B.C., Edgett, K.S., Ehlmann, B.L., German, C.R., Hayes, A.G., Hoehler, T.M., Horst, S.M., Lunine, J.I., Nealson, K.H., Paranicas, C., Schmidt, B.E., Smith, D.E., Rhoden, A.R., Russell, M.J., Templeton, A.S., Willis, P.A., Yingst, R.A., Phillips, C.B., Cable, M.L., Craft, K.L., Hofmann, A.E., Nordheim, T.A., Pappalardo, R.P., and the Project Engineering Team (2017): Report of the Europa Lander Science Definition Team. Posted February, 2017.

[2] Campagnola, S., B. B. Buffington, A. E. Petropoulos. (2013) "Jovian tour design for orbiter and lander missions to Europa." 23rd AAS/AIAA Space Flight Mechanics Meeting. Kauai, HI. AAS 13-494.

[3] Lynnae & S. Barnouin, Olivier & Wesley Patterson, G & M. Prockter, Louise. "Constraints on the Detection of Cryovolcanic Plumes on Europa." Planetary and Space Science 86 (2013) 1-9. © 2013 Elsevier Ltd.

[4] Pappalardo, R.T., S. Vance, F. Bagenal, B.G. Bills, D.L. Blaney, D.D. Blankenship, W.B. Brinckerhoff, et al. "Science Potential from a Europa Lander." Astrobiology 13, no. 8 (August 2013): 740-773. © 2013 Mary Ann Liebert, Inc.

[5] Brent Buffington. "Trajectory Design Concept for the Proposed Europa Clipper Mission (Invited)", AIAA/AAS Astrodynamics Specialist Conference, AIAA SPACE Forum, (AIAA 2014-4105).

BIOGRAPHY

Jennifer Dooley *is a system engineer at the Jet Propulsion Laboratory. She began working at JPL in 1997 on magnetostrictive materials for use in cryogenic actuators and dampers. Since then she has supported a number of missions in implementation and formulation, from the cryogenic testing of the Spitzer telescope to serving as the instrument system engineer for CheMin on and currently is the lead system engineer for the Europa Lander pre-project study. She has a BS in Applied Physics from Caltech and an MS & PhD from Carnegie Mellon University.*